

Arm-ankle systolic blood pressure difference at rest and after exercise in the assessment of aortic coarctation

Jan Engvall, Christine Sonnhag, Eva Nylander, Göran Stenport, Erling Karlsson, Bengt Wranne

Abstract

Objective—To evaluate the difference in systolic blood pressure at the arm and ankle at rest and after various exercise tests for the assessment of aortic coarctation.

Methods—22 patients (mean age 33 years, range 17–66) were investigated on the suspicion of having haemodynamically significant aortic coarctation. Eight had undergone previous coarctation surgery, of whom five had received vascular grafts and three end to end anastomoses. The patients exercised submaximally while supine, seated on a bicycle, and walking on a treadmill, as well as exercising maximally on a treadmill. Arm and ankle blood pressure were measured with a cuff at rest and 1–10 minutes after exercise. Invasive pressures and cardiac output by thermodilution were recorded during catheterisation while patients were at rest and during and after supine bicycle exercise. The degree of constriction was assessed by angiography. Twelve healthy volunteers (mean age 32 years, range 17–56) provided reference values for cuff pressures after exercise.

Results—All patients with a difference in cuff pressure at rest of 35 mm Hg or more had a difference in invasive pressure of 35 mm Hg or more. Increasing severity of constriction on angiography correlated with larger pressure gradients at rest and during exercise ($P < 0.0001$). When cuff measurements after exercise were considered singly or combined to form a predictor they did not improve the prediction of the invasive pressure gradients at rest or after maximal exercise. A pressure gradient between arm and ankle also developed in normal subjects after maximal but not after submaximal exercise.

Conclusion—In most patients with suspected haemodynamically significant coarctation the difference in cuff pressure between arm and ankle at rest is sufficient to select patients in need of further evaluation. If exercise is performed submaximal exercise is preferable.

Technological imperative demands that the latest, most advanced methods be used to assess cardiac disease. Doppler echocardiography, including the transoesophageal approach, and magnetic resonance imaging, are such methods for assessing coarctation of the aorta. Whether they are necessary, cost effective, or superior to old methods remains to be proved. The difference in systolic pressure between arm and ankle has been widely used clinically to predict the central aortic pressure difference, but the accuracy of this test has been debated.^{1–3} We assessed whether this method should be retained in diagnosing coarctation of the aorta, and whether measurements after exercise provide additional information.

Connor suggested that a pressure difference of 35 mm Hg or more after treadmill exercise is a cut off point for suspecting a haemodynamically significant recoarctation. This was based on the largest pressure difference measured non-invasively in patients without coarctation and the smallest non-invasive pressure difference in patients with a verified coarctation. We previously reported pressure differences of up to 95 mm Hg in normal subjects after a maximal treadmill test.⁴ Hanson *et al* did not find a significant correlation between the invasive pressure difference and angiographic degree of constriction.² Using an automated blood pressure device, Wendel *et al* found only a weakly positive correlation between the invasive and non-invasive pressure difference measured simultaneously after exercise.³

Realising that the pressure difference across a constriction is related to flow, we investigated the workload and type of exercise that could best predict the invasive results, with the aim of devising an appropriate screening test to select patients for further investigation.

Patients and methods

PATIENTS

Twenty two consecutive patients (nine women and 13 men (mean age 33 years; range 17–66)) were investigated when they were suspected of having a coarctation or recoarctation of the aorta. Suspicion was based on arterial hypertension and a positive pressure difference between arm and ankle at rest or after exercise. Clinical data, pressure gradients, and angiographic findings are listed

Departments of
Clinical Physiology,
Cardiology, and
Thoracic Radiology,
Linköping University
Hospital, Linköping,
Sweden

J Engvall
C Sonnhag
E Nylander
G Stenport
E Karlsson
B Wranne

Correspondence to:
Dr J Engvall, Department of
Clinical Physiology,
Linköping University
Hospital, S-581 85
Linköping, Sweden.

Accepted for publication
7 July 1994

(Br Heart J 1995;73:270–276)

Keywords: blood pressure; coarctation; exercise

Table 1 Clinical data on, pressure gradients in, and angiographic assessment of the coarctation in 22 patients with coarctation.

Difference in pressure (mm Hg):									
Case No	Sex	Age (years) at study	Surgery	At rest		On exercise		Constriction at angiography (%)	Miscellaneous
				Invasive	Cuff	Invasive*	Cuff†		
1	M	29	16	24	10	59	55	≥ 50	Graft
2	M	31	—	4	—15	26	—10	< 50	Aortic regurgitation grade IV
3	M	59	—	53	55	—	120	> 75	Aortic regurgitation grade III
4	F	40	8	15	5	48	75	≥ 50	
5	F	23	—	0	15	10	50	< 50	“Kinking”
6	F	18	—	15	0	64	65	< 50	
7	F	23	10	61	60	109	140	> 75	Abdominal graft
8	M	43	24	32	15	81	60	< 50	Graft
9	F	32	8	3	0	17	30	< 50	
10	M	47	19	14	—20	48	135	< 50	Homograft with aneurysm close to the anastomosis
11	M	50	—	43	40	98	65	> 75	
12	F	35	—	52	50	98	110	> 75	
13	F	26	—	0	—30	—	45	0	Only slight pulmonary stenosis
14	M	17	—	89	65	117	80	> 75	Aortic regurgitation grade IV
15	M	21	—	0	0	—	65	0	No coarctation
16	M	19	—	0	—10	0	50	0	No coarctation; primary hypertension
17	M	66	—	52	50	74	105	> 75	Coronary revascularisation one year earlier
18	M	32	10	10	—10	30	35	< 50	Aortic regurgitation grade III
19	M	37	10	22	5	—	15	< 50	Aortic regurgitation grade IV
20	M	26	—	44	40	103	100	> 75	
21	F	24	—	58	65	105	85	> 75	Operative closure of ductus at one year of age
22	F	18	—	58	60	86	85	> 75	

*Difference in peak to peak systolic pressure during peak practice.

†Difference in systolic pressure at arm and ankle one minute after submaximal treadmill exercise.

in table 1. Eight patients had previously undergone vascular reconstructive surgery at a mean age of 13 years. Five of these had received a vascular graft, and three had had a resection with an end to end anastomosis.

The evaluation included comprehensive Doppler echocardiography, bicycle exercise testing while the patient was supine and seated, and submaximal and maximal treadmill exercise testing one to two days before catheterisation and angiography. We have published reference values for the blood pressure difference after submaximal and maximal treadmill exercise.² Twelve of these volunteers also performed bicycle exercise testing while supine and seated and their results are used as the reference in this study. Their mean age was 32 (12) years (range 17–56). They did not report any symptoms of cardiovascular disease, and they had a normal digitogram (volume pulse recording of the big toe). The study was approved by the ethics committee of the university, and informed consent was obtained.

CATHETERISATION

Right heart catheterisation was performed by introducing a 7F thermodilution catheter preferably through a vein in the right cubital fossa or through the right femoral vein. Two 5F end hole arterial catheters were inserted, one from the right brachial artery to the aortic arch and the left ventricle, the other from the left groin to a distance of about 15 cm downstream of the coarctation. Pressure was recorded through transducers calibrated against a hydrostatic reference. The amplitude response of the arterial measuring system was flat up to 20 Hz. Cardiac output by thermodilution (injection of 10 ml cold saline, mean of three determinations, Sirecust, Siemens Corporation, Erlangen, Germany)

was recorded at rest and during two levels of exercise identical with the supine bicycle exercise test. During exercise an electronically braked bicycle was attached to the lower end of the catheterisation table. After exercise blood pressure and cardiac output by thermodilution were measured as frequently as possible; 1, 2, 3, 5 and 10 minutes after exercise. Four patients did not undergo exercise testing, two because they were bleeding at the puncture site in the groin and the third because of difficulties in entering the brachial artery. Angiography through the femoral catheter in this last patient did not show a coarctation. The fourth patient developed a temporary third degree atrioventricular block and catheterisation was therefore interrupted.

ANGIOGRAPHY

Angiography was performed through the femoral or the brachial artery after exercise. In 19 patients cross sectional views of the coarctation were recorded on cine film, and in three patients a single view was recorded. In an off line review the degree of constriction was visually assessed on the basis of the aortic diameter related to the immediate upstream aortic segment. The cine film was assessed according to four categories: ≥75% reduction in diameter, 75–50% reduction, <50% reduction, or a normal lumen without constriction. Aortic regurgitation was assessed in a semi-quantitative fashion according to the method of Cullhed, in which 0 is no regurgitation and IV is filling of the whole left ventricle on the first beat.⁵

NON-INVASIVE MEASUREMENT OF BLOOD PRESSURE

Systolic blood pressure was measured in the upper arm and ankle bilaterally with a continuous wave Doppler device (Parks Medical

Electronics, Beaverton, Oregon, USA) that evaluated systolic flow signals in the brachial and posterior tibial arteries, respectively. The same standard cuff (12 × 35 cm) was used for both locations, cuff width always being at least 40% of arm or ankle circumference. The arm and the leg with the higher systolic pressure were then selected for simultaneous measurement. During exercise arm systolic blood pressure was recorded every two to three minutes with the arm raised to the level of the heart. Blood pressure was measured while patients were supine 1, 2, 3, 5, and 10 minutes after the end of exercise according to our previously described protocol.²

TREADMILL EXERCISE TESTING

A motorised treadmill was used (Quinton Instruments, Seattle, Washington, USA). Submaximal (final load 2 W/kg) and symptom limited maximal exercise tests were performed on the same day as described earlier.² Load was calculated as the sine of the angle of elevation × body weight (kg) × velocity (m/s) × 9.81.

SEATED BICYCLE EXERCISE

An electronically braked bicycle (Siemens-Elma, Sweden) was used. The test began at a load of 50 W, which was increased by 10 W each minute until the test was interrupted at a predetermined load of 2.5 W/kg. Blood pressure was measured simultaneously in the arm and at the ankle while patients were recumbent. During exercise blood pressure and perceived exertion⁶ were determined.

SUPINE BICYCLE EXERCISE

On the basis of the maximal treadmill test, the final load was converted to an equivalent load for 6 minutes of steady state exercise.⁷ Two levels, 40% and 60%, of maximal load, were selected for supine exercise which was identical with that during cardiac catheterisation. The patients exercised for six minutes on the first load and then immediately continued to the next level for another six minutes. Systolic blood pressure and ratings of exertion were recorded every two minutes. After exercise blood pressure was determined simultaneously in the arm and at the ankle.

STATISTICS

Group results are expressed as mean (SD). Student's *t* test for paired and unpaired com-

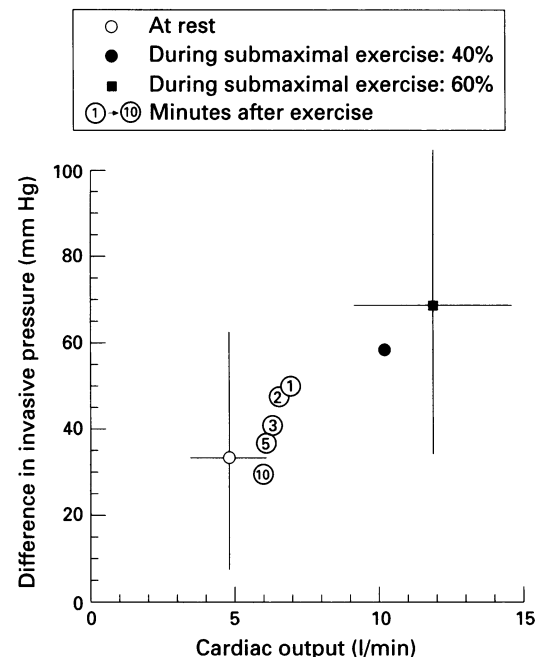


Figure 1 Cardiac output by thermodilution and central difference in systolic blood pressure in patients with coarctation. Values are means, the vertical and horizontal lines showing SD at rest and at 60% of maximal capacity. Values are missing for two patients at rest, for four during exercise, and for eight after exercise; four patients did not undergo exercise testing for health reasons.

parisons, one factor analysis of variance, linear regression, and correlation analyses were used. Agreement between methods was assessed according to the method of Bland and Altman.⁸

Results

CATHETERISATION

Invasive pressures are summarised in table 2. There was a close correlation between the maximal difference in systolic pressure during exercise and at rest ($y = 1.25x + 27$, $r = 0.93$, standard error of the estimate (SEE) 5.5), as well as one minute after exercise compared with rest ($y = 0.97x + 17.9$, $r = 0.91$, SEE 4.89) and one minute after exercise and peak ($y = 0.74x - 0.90$, $r = 0.93$, SEE = 5.7). The mean difference in systolic pressure measured invasively increased from 35 (28) mm Hg at rest to 69 (35) mm Hg during exercise, which correlated linearly with the mean increase in cardiac output. After exercise cardiac output fell quickly while the blood pressure gradient diminished more slowly (figure 1).

Table 2 Mean (SD) cuff and invasive systolic blood pressure at rest, at peak exercise, and one minute after exercise in 19 patients with verified coarctation

	Blood pressure (mm Hg)										Rate of perceived exertion non-invasive
	Proximal		Distal		Difference		Heart rate		Workload (W)		
	Invasive	Cuff	Invasive	Cuff	Invasive	Cuff	Invasive	Cuff	Invasive	Cuff	
At rest	159 (26)	162 (22)	125 (22)	136 (28)	35 (28)	26 (29)	67 (13)	68 (12)			
At peak:											
Supine bicycle exercise	199 (25)	205 (28)	130 (31)		69 (35)		122 (19)	120 (19)	95 (25)	92 (25)	14 (2)
Submaximal treadmill exercise		223 (41)						147 (23)		141 (27)	14 (2)
Maximal treadmill exercise		238 (40)						165 (21)		193 (48)	18 (1)
Seated bicycle exercise		245 (28)						155 (21)		164 (23)	16 (2)
1 Minute after:											
Supine bicycle exercise	170 (23)	173 (24)	117 (22)	115 (31)	53 (26)	58 (33)	95 (22)	90 (20)			
Submaximal treadmill exercise		209 (39)		136 (36)		74 (39)		102 (22)			
Maximal treadmill exercise*		233 (40)		131 (42)		102 (40)		122 (20)			
Seated bicycle exercise		225 (29)		126 (41)		99 (35)		98 (23)			

*18 patients.

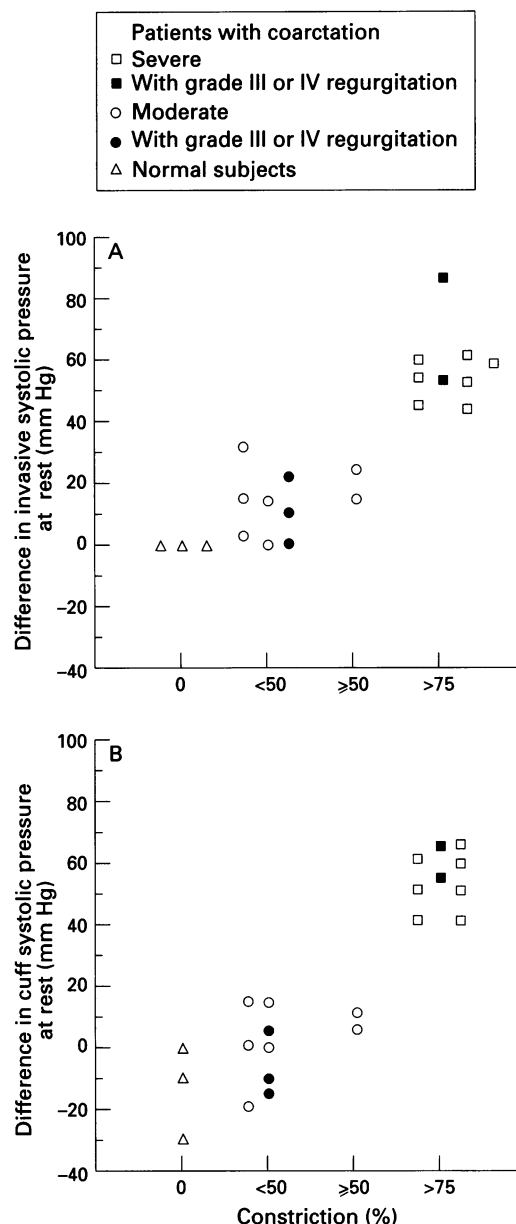


Figure 2 Top: Difference in invasive central pressure at rest plotted against degree of constriction assessed by angiography. Bottom: Difference in cuff systolic pressure between arm and ankle at rest versus degree of constriction. The normal subjects had an exaggerated blood pressure response at exercise. There is a positive correlation between increasing severity of constriction and increasing pressure difference in both comparisons ($P < 0.0001$).

Nine patients had a severe constriction with a reduction in aortic diameter greater than 75%, two had a reduction between 75% and 50%, and eight had a reduction of less than 50% (table 1). At rest patients with a more severe constriction had a larger difference in central systolic blood pressure measured invasively ($P < 0.0001$) (figure 2). The same was true during exercise (data not shown). There was a weaker relation between the degree of constriction and invasive proximal and distal pressures at rest; there was no significant relation between the constriction and the maximal invasive systolic upstream blood pressure attained during exercise. Five patients (two of whom had had coarctation surgery) had aortic regurgitation of grade III or IV. Only three

out of eight patients with suspected recoarctation had a reduction in diameter greater than 50%.

CUFF BLOOD PRESSURE COMPARED WITH INVASIVE PRESSURE AT REST

Cuff pressures are summarised in table 2 and figure 3. At rest the difference in systolic pressure measured with a cuff and that measured invasively correlated closely (regression equation $y = 1.08x - 11.9$, $r = 0.93$; figure 4, table 3). The interval of agreement (the difference between invasive and cuff pressure) was 8.3 (12.1) mm Hg (figure 4). An arm to ankle difference in cuff pressure of 35 mm Hg or more identified all the patients with an invasive pressure difference of equal magnitude, with a specificity of 100% (figure 4).

SUPINE BICYCLE EXERCISE

The average final workload was 92 (25) W (range 50–130 W). The mean perceived exertion was 14 (2), or moderately strenuous (range 11–17) on a 15 step scale of 6 to 20, in which 17 is very strenuous.⁶ The correlation of the arm-ankle difference in cuff pressure one minute after exercise correlated moderately well with the difference in invasive pressure at maximal exercise, one minute after exercise, and at rest (table 3). Compared with the reference group, the patients exercised on a lower load (92 (25) W *v* 110 (22) W), had a larger difference in cuff pressure one minute after exercise (58 (33) *v* 5 (13)), but they rated perceived exertion similarly (14 (2) *v* 15 (1)).

SUBMAXIMAL TREADMILL EXERCISE

Submaximal exercise was on average 141 (27) W or 76% of the patients' maximal exercise capacity. Exertion was rated 14 (2) (range 11–18). The difference in systolic pressure between arm and ankle one minute after exercise was 74 (39) mm Hg; the correlation with the difference in invasive pressure at maximal exercise was low (table 3). Two patients stopped before the final load on the submaximal exercise test because of leg fatigue, whereas all subjects in the reference population completed exercise with an average final work load of 135 (17) W. This was, on average, 60% of their maximal load in the maximal test. Ankle systolic blood pressure was higher than arm pressure in all volunteers except one, who had an ankle pressure 10 mm Hg lower than his arm pressure. Ratings of exertion were similar to those of the patients.

MAXIMAL TREADMILL EXERCISE

Maximal exercise capacity was 193 (48) W, which is 112% (26%) of the reference value for bicycle exercise.⁹ Arm pressure was on average 102 (40) mm Hg higher than the ankle pressure one minute after exercise. The correlation of the difference in cuff systolic pressure with the difference in invasive pressure at maximal exercise, one minute after exercise, and at rest were low. Perceived

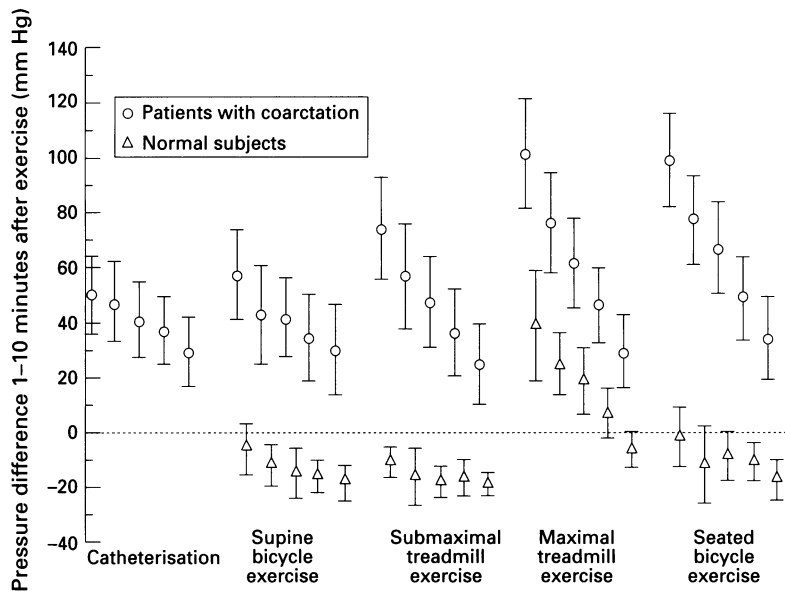
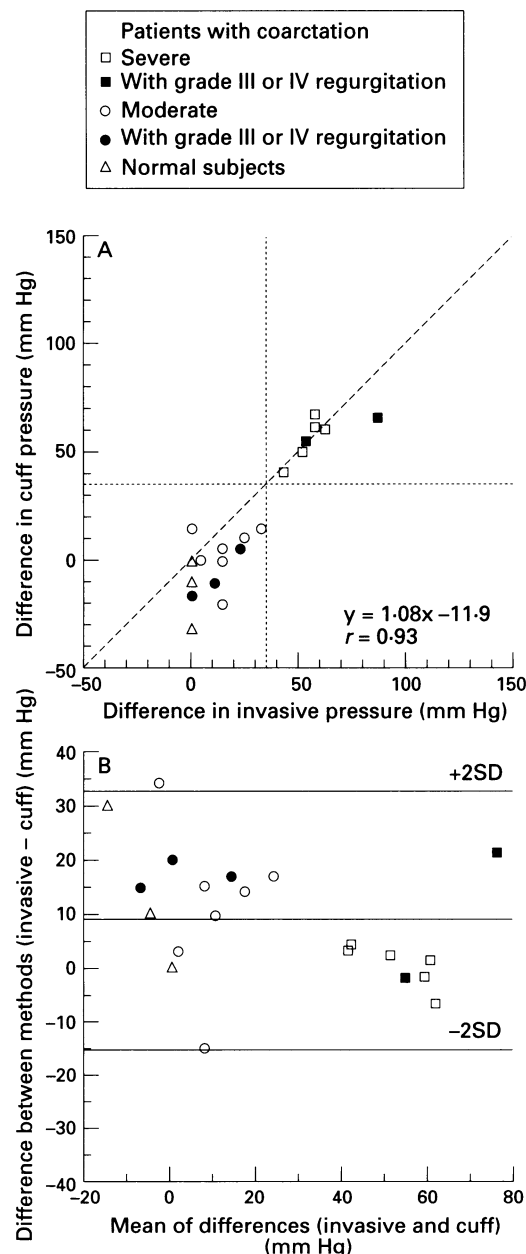


Figure 3 Mean differences in blood pressure measured 1, 2, 3, 5, and 10 minutes after the various exercise tests. Vertical lines show 95% confidence intervals.

Figure 4 Top: Difference in cuff systolic pressure between arm and ankle versus difference in invasive central systolic pressure at rest. Dashed line indicates $y = x$. Bottom: mean difference between methods with 2SD versus their mean, according to Bland and Altman.⁸



exertion was slightly lower than that in the reference group (18 (2) v 19 (1), $P = 0.0036$), who also exercised to a higher final load (230 (50) W).

SEATED SUBMAXIMAL BICYCLE EXERCISE

Five patients did not perform exercise at 2.5 W/kg; they stopped at 1.3–2.2 W/kg, four because of leg fatigue and one because of general fatigue. The average load was 164 (23) W (168 (22) W in the reference group) and exertion 16 (2) (15 (2) in the reference group) (table 2). The difference in cuff blood pressure between arm and ankle after exercise was 99 (35) mm Hg and correlated poorly with invasive pressure at maximal exercise, one minute after exercise, and at rest.

CORRELATION OF CUFF AND INVASIVE PRESSURE DIFFERENCE AT REST

In figure 5 the difference in systolic pressure at arm and ankle after treadmill and bicycle exercise is plotted against the difference in invasive pressure at rest and during maximal exercise. A difference of 35 mm Hg in cuff pressure after exercise, as in the paper by Connor,¹ identified all subjects with a difference in invasive pressure at rest of more than 35 mm Hg, but a large number of false positive results were also found (figure 5, upper), including the three patients without coarctation. In a multiple regression analysis of the relation between patient variables and the difference in invasive blood pressure at rest, only the angiographic degree of constriction showed a significant positive correlation ($P = 0.0008$). Of the differences in cuff pressure after exercise, none contributed to the prediction of the difference in invasive pressure. The equation $f(x) = 0.8 \times (\text{cuff pressure difference at rest}) + 0.2 \times (\text{cuff pressure difference after submaximal treadmill exercise} - \text{cuff pressure difference after seated bicycle exercise})$ predicted a difference measured invasively at rest of more than 35 mm Hg with 100% sensitivity and specificity. This was not, however, better than the measurement of the difference in cuff pressure at rest alone.

CORRELATION OF CUFF AND INVASIVE PRESSURE DIFFERENCE AT MAXIMAL EXERCISE

Blood pressure measurements one minute after submaximal treadmill exercise identified all 11 patients with an invasive pressure difference exceeding 50 mm Hg, with only two false positive results. These two patients had, in fact, a pressure difference very close to 50 mm Hg (figure 5, bottom (submaximal treadmill exercise)). The other exercise tests gave more false positive results, and supine bicycle exercise also gave one false negative result.

Three patients did not have an aortic coarctation. They were included at the beginning of the study on the basis of an abnormal difference in blood pressure between arm and ankle after exercise. The increase in this difference after exercise was mainly caused by an exaggerated increase in systolic arm pressure. Their results are shown in figure 5 (as Δ).

Table 3 Regression equations for differences in cuff pressure *v* differences in invasive pressure

	k	Intercept	r	SEE
Invasive peak <i>v</i> invasive rest	1.25	27.0	0.93	5.5
Invasive 1 minute after peak <i>v</i> :				
Invasive rest	0.97	17.9	0.91	4.89
Invasive peak	0.74	-0.89	0.93	5.7
Cuff rest <i>v</i> invasive rest	1.08	-11.9	0.93	3.9
Cuff 1 minute after supine bicycle exercise <i>v</i> :				
Invasive rest	0.87	27.0	0.64	10.1
Invasive peak	0.56	20.4	0.66	12.7
Invasive 1 minute after peak	0.75	21.4	0.70	11.2
Cuff 1 minute after submaximal treadmill exercise <i>v</i> :				
Invasive rest	0.93	43.2	0.61	11.5
Invasive peak	0.68	27.6	0.62	17.1
Invasive 1 minute after peak	0.78	35.4	0.56	16.8

k, inclination of the regression line.

intercept, y value when x is 0.

r, regression coefficient.

SEE, standard error of the residual.

Discussion

The symptoms and signs of aortic coarctation are well known, and the diagnosis and the severity of the constriction can be established today by non-invasive methods. Echocardiographic imaging and Doppler ultrasonography in extracardiac lesions may, however, still be technically difficult. Although magnetic resonance imaging circumvents some of the problems of accessibility, this method also has limitations and drawbacks (our unpublished data). A fundamental principle of non-invasive testing is to sum information obtained with different methods to achieve

the highest possible diagnostic accuracy. Measurement of blood pressure with a cuff is an additional non-invasive method that has been used for decades, but views continue to vary about its value in assessing patients with aortic coarctation.^{3 10} In our study the pressure difference across the coarctation, measured both in connection with catheterisation and with the cuff technique, carried a high sensitivity and specificity for identifying patients with a reduction in diameter of more than 50% at angiography.

There was excellent agreement between the pressure difference between arm and ankle measured with a cuff at rest and the pressure difference found invasively. This pressure difference also significantly correlated with the angiographic degree of stenosis. In fact, a pressure difference above 35 mm Hg identified all patients with angiographically severe constrictions. This is in contrast to findings by Hanson *et al.*² In our study the degree of coarctation varied widely, which makes a statistical relation easier to identify; all the patients in the study of Hanson *et al* had a rather wide anastomosis after coarctation surgery. Patients with aortic regurgitation have an exaggerated negative pressure difference between arm and ankle, probably owing to a larger influence of reflected waves.¹¹ This could possibly reduce the pressure difference due to aortic coarctation. However, our

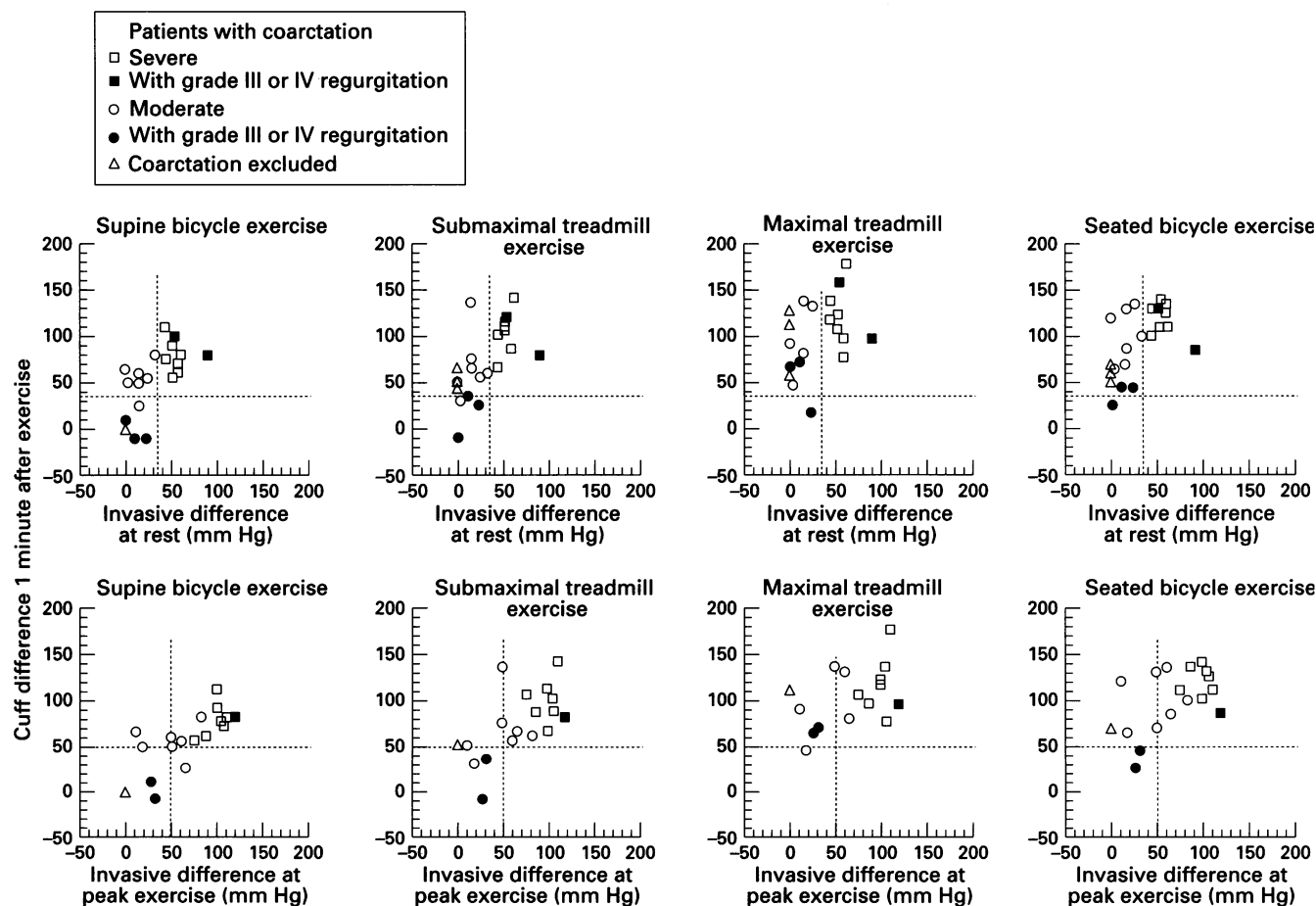


Figure 5 Difference in cuff pressure one minute after exercise compared with the difference in invasive central pressure at rest (top row) and at peak exercise (bottom row). Two data points overlap in the graphs for maximal treadmill exercise. The dashed lines on the top row show a pressure difference of 35 mm Hg for cuff as well as invasive measurement. The dashed lines in the bottom row show a pressure difference of 50 mm Hg for cuff as well as invasive measurement.

patients with clinically significant aortic regurgitation and a low pressure difference between arm and ankle at rest did not have severe coarctation on angiography.

The pressure difference across the coarctation varied with cardiac output as seen in figure 1. We hypothesised that the diagnostic criteria for aortic coarctation could be sharpened if the pressure difference was also measured in connection with an increased cardiac output. Cuff measurements of leg pressure during exercise are not feasible, but immediately after exercise altered haemodynamic conditions should persist. Pressure difference one minute after exercise was therefore chosen in addition to the values at rest.

We tested three different types of submaximal exercise in addition to maximal exercise to see whether the cuff pressures one minute after exercise could be used as substitutes for invasive exercise pressures. The correlation between these values one minute after exercise and the maximal exercise invasive pressure difference or difference at rest were all rather weak. The invasive procedure could possibly cause a higher degree of sympathetic stress in the patients and therefore an altered vascular tone and blood pressure difference, which has been shown to be important during invasive ambulatory monitoring.¹² Another contributory factor could be the clearly different relation between the pressure difference and cardiac output after exercise (figure 1). It is noteworthy that the cuff gradient obtained after the submaximal tests differed significantly between patients and normal controls (figure 4), while there was an overlap between the patients with coarctation and the reference group after the maximal treadmill test.

Connor suggested that a blood pressure difference of 35 mm Hg after maximal treadmill exercise in a population of patients after surgery for coarctation could be evidence of recoarctation, but the load attained was not specified.¹ Connor showed that the pressure difference after exercise varies with type and degree of exercise. We found that, even with the submaximal treadmill test, the application of a limit of 35 mm Hg may lead to many false classifications in a mixed population of patients. Moreover, we found three patients who fulfilled Connor's criteria for coarctation but did not have one. However, a cut off point of 50 mm Hg after submaximal treadmill exercise permitted a better separation of patients. Markel *et al* compared the effects of exercise on arms and legs and hypothesised that in patients with significant aortic narrowing exercising the leg produced a larger drop in pressure than exercising the arm because of an increased flow across the repair site.¹⁰ However, the pressure drop is dependent on the resistance in the parallel flow beds of the upstream circulation, and the resulting interaction is difficult to predict.¹³

The question arises whether exercise testing in patients with coarctation is indicated. For diagnosis and decision making about surgical treatment of a native coarctation, other non-invasive modalities are usually sufficient.

Nowadays the diagnosis is often made in infancy or early childhood, although some cases are not diagnosed until adulthood. Furthermore, there is a growing population of adults who have been operated on at different ages by different methods. The need for life-long follow up exists not only for the adequate care of individual patients but also for an ultimate, scientifically based decision about surgical technique and timing to achieve the optimal long term result. Such evaluations should preferably contain not only anatomical but also haemodynamic information. The exercise test carries information about the systolic blood pressure response proximal to the coarctation. We found that even at submaximal exercise the mean upstream systolic blood pressure was in excess of 200 mm Hg, which exceeds the reference value for this age group.⁹ The difference in non-invasive blood pressure between arm and ankle depends on factors such as peripheral vascular resistance, cardiac output, and collateral flow when present, as well as the degree of aortic narrowing. With this in mind, we believe that the blood pressure difference during exercise can be a useful haemodynamic parameter suitable for long term follow up of patients who have had surgery for coarctation.

Our results emphasise the importance of standardisation of the type and intensity of the exercise used in conjunction with blood pressure measurement in patients with coarctation.

We thank Inger Ekman, Elisabet Forsström, and Birgitta Lönnqvist for their help with the patients, and Erik Leander for statistical advice. Financial support was given by the County Council of Östergötland, the Research Foundation of the University Hospital, the Swedish Heart-Lung Foundation, and the Swedish Medical Research Council (grant 9481).

- 1 Connor TM. Evaluation of persistent coarctation of the aorta after surgery with blood pressure measurement and exercise testing. *Am J Cardiol* 1979;43:74-8.
- 2 Hanson E, Erikson B, Sörensen SE. Intraarterial blood pressures at rest and during exercise after surgery for coarctation of the aorta. *Eur J Cardiol* 1982;11:245-57.
- 3 Wendel H, Teien D, Human DG, Nanton MA. Assessment of blood pressures and gradients by automated blood pressure device compared to invasive measurements in patients previously operated on for coarctation of the aorta. *Clin Physiol* 1992;12:155-62.
- 4 Engvall J, Nylander E, Wranne B. Arm and ankle blood pressure response to treadmill exercise in normal people. *Clin Physiol* 1989;9:517-24.
- 5 Cullhed I. Aortic stenosis: a clinical study of aortic stenosis, isolated or combined with aortic insufficiency, with special reference to haemodynamic and angiographic observations [thesis]. Uppsala: University of Uppsala, 1964:95.
- 6 Borg G. Psychophysical basis of perceived exertion. *Med Sci Sports Exerc* 1982;14:377-81.
- 7 Åström H, Jonsson B. Design of exercise test, with special reference to heart patients. *Br Heart J* 1976;38:289-96.
- 8 Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986;i:307-10.
- 9 Nordenfelt I, Adolfsson L, Nilsson JE, Olsson S. Reference values for exercise tests with continuous increase in load. *Clin Physiol* 1985;5:161-72.
- 10 Markel H, Rocchini A, Beekman R, Martin J, Palmisano J, Moorehead C, *et al*. Exercise-induced hypertension after repair of coarctation of the aorta: arm versus leg exercise. *J Am Coll Cardiol* 1986;8:165-71.
- 11 Enghoff E. Aortic incompetence: clinical, haemodynamic and angiographic evaluation [thesis]. Uppsala: University of Uppsala, 1972:46.
- 12 Sehested J. Differences in circadian blood pressure between upper and lower extremity in aortic coarctation patients with and without postoperative pressure gradients. *Am J Cardiol* 1992;69:382-6.
- 13 Engvall J, Karlsson M, Ask P, Loyd D, Nylander E, Wranne B. Importance of collateral vessels in aortic coarctation. *Med Biol Eng Comput* 1994;32:S115-22.